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CATHODIC PROTECTION STUDIES, November 1953 to November 1954

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SUMMARY

A graphite anode cathodic protection (CP) system on a group of ten hulls utilizing current control in individual hull return lines was installed and maintained through the subject period. An experimental electronic servo system has served automatically to control the total CP current for six months. The results of experimentation with several types of commercial and laboratory-fabricated reference cells indicate the need for additional development of a reference cell for continuous use.

Maintenance requirements of the system after approximately 2-1/2 years of operation have increased for the underwater components. Deterioration of the anode and seal at the lead connection end and lead cables has seriously reduced the reliability of the system. These difficulties were due in part to the lack of mechanical protection for the cables and anodes subjected to shoreline and bottom abrasion and in part to an inferior method of attaching the anode lead to the anode.

The addition of resistance controls on a magnesium anode system for an operating drydock provides longer anode life, closer control of the polarization level, and more uniform current distribution. The disadvantages of the magnesium system result from the need for a closer monitoring schedule due to the low voltage available and the life and number of anodes required.

The effectiveness of CP is being determined by photographic, mold, and coupon methods used before and after intervals of protection.

Test facilities for a study of the compatibility of painted coatings and of floating corrosion inhibiting coatings in conjunction with CP are described.

INTRODUCTION

Laboratory investigations of cathodic protection (CP) techniques commenced under Project NY 450 004 in November 1950. The initial installation was made on the AFDL-12, a 1000-ton floating drydock, using a single centrally located graphite anode at a total cost of $400.00. This installation and a discussion of the principles of CP were reported in Reference 1. Additional observations and effectiveness data were presented on the AFDL-12 in Reference 2. The corrosion rate on protected coupons indicated a reduction from 125 gms/sq ft/yr to 17 gms/sq ft/yr using a protective current of approximately eight amperes.

A multiple hull graphite system was installed on the AFDB-4, a 7-section drydock, in the spring of 1952 to investigate the problems associated with the simultaneous protection of several hulls. Anodes were placed on the harbor bottom. Current control was obtained by the positioning of anodes and by use of rheostats in the anode leads. A magnesium anode system was devised for the AFDL-20 and installed in May 1952. Initially, one 51-pound anode provided adequate protection for this hull with no current control used. Additional details and data relative to cost, effectiveness, and equipment are described in Reference 3.

Monitoring (scheduled at weekly intervals) and maintenance of these installations continued during 1953. Effectiveness data obtained during this period from test coupons indicated corrosion had been reduced to a negligible amount on the multiple hull system, and a reduction of about 80% was achieved on the AFDL-20. A program of recording the condition of the underwater hull surfaces of the AFDB-4 during quinquennial reconditioning was commenced to obtain additional effectiveness data. The addition of the YR-46 and the YR-50 and the termination of the single anode system on the AFDL-12 resulted in combining these ships with the AFDB-4 into one system. Recommendations for improving current control by installing rheostats in the individual ground return leads were made for this system. Resistance controls and additional anodes were installed in the magnesium anode system on the AFDL-20 to provide accurate current adjustment and longer anode life. Reference 4 describes these modifications and data for both installations.

The data and observations presented in the above-mentioned reports have formed the background for equipment and design considerations necessary to provide adequate protection. Results obtained to date have substantiated the efficacy of using CP techniques in conjunction with painted coatings for the corrosion mitigation of drydock hulls. The additional factors of maintenance, reliability, and cost to achieve optimum protection can only be obtained through experience over long periods. Continued development of component parts is being conducted simultaneously with operation of the described installations.

The use of CP currents and the resulting polarization effects upon paint coatings has instigated a Laboratory test investigation of the compatibility of various coatings in conjunction with CP. This test began in October 1954.

An additional test facility to evaluate the use of float coatings with CP in tank compartments is proposed for early installation.

LONG BEACH MULTIPLE HULL SYSTEM

The Long Beach installation was modified and combined as proposed in Reference 4 and has been operating since February 1954 as shown in Figure 1. Electrical power is supplied by one rectifier, and the anodes are supplied current from a positive buss, thus tending to put each anode at the same potential. A control panel providing individual control and measurement of the hull return currents was installed in February 1954. The control panel is shown in Figure 2. This method of control has the advantages of providing a positive current adjustment and an accurate record for each hull and being conducive to uniform anode current regardless of hull requirements in the immediate vicinity of the anode.

The current and polarization records are presented in Figures 3a and 3b. The large current fluctuations resulted from several factors. The large variation in December was caused by replacement and testing of new selenium stacks in the main rectifier; during which time auxiliary rectifiers could not provide sufficient current. From January through April considerable movement of the various AFDB-4 Sections occurred requiring discrete manual current adjustments not normally encountered in a stable system. In May an electronic servo current control system, described elsewhere in this report, was installed and has remained in continual operation except for minor changes. Experimentation with this unit and additional changes in the hull mooring habits contributed to the fluctuations recorded until November. As the AFDB-4 Sections returned from their quinquennial reconditioning, the current requirements for the individual hulls decreased from a maximum of 30 amperes before to about 3 amperes after reconditioning. The average polarization has been maintained in general between 760 and 900 millivolts ($Cu/CuSO_4$), as compared with the generally accepted value of 850 millivolts for painted structures. The factors contributing to the differences from the desired 850 millivolt value can be divided into two groups: (1) The distant location of the installation from the Laboratory creates a transportation and time allocation problem. A weekly survey and inspection of the facility is scheduled; however, project personnel are not always informed when sections are removed, and on several occasions ground return lines have been disconnected or changed inadvertently by yard workmen. Failures in the system (such as damage to anode or ground return leads and power failure) are determined at weekly intervals instead of immediately; (2) The inherent limitations of adjustment when experimenting with new control methods and anode locations result in abnormal fluctuations.

Individual current requirements are measured weekly, using the shunts and meter in the ground return leads. The current values are average values since variations in temperature and weather (rough water increases the wave action and movement of the hull causing some depolarization) influence the resistance of the electrical path. Current measurements made in this manner can be justified as accurate indications of the effective current to the individual hulls because, as shown in Reference 3, the resistance of the sea water is of the same magnitude as the resistance of a well bonded #4 AWG bonding cable. The measured resistance of the inter-hull mooring chains is large compared with the resistance of the sea water. Figure 4 represents a plot of the individual currents required by the AFDB-4 Sections vs time out of drydock. The displacement of the various currents from a smooth curve is attributed to differences in time out of drydock before protection was applied and differences in initial current due to relatively small imperfections in the paint system. Data on the initial current supplied to Section D was not taken prior to the installation of the control panel in February 1954. The average protection current for this hull has increased slightly (approximately 1 ampere) in the intervening nine months, indicating the initial current was higher due to the longer period between reconditioning and the application of current. The interval between reconditioning and return of the hull to the CP system is dependent upon the Yard work schedule for topside maintenance. All hulls were placed under protection within one week after returning to their regular mooring site. The use of a temporary galvanic type CP system during the period between reconditioning and the return of the hull to the permanent CP system appears to be desirable when this time interval is greater than two or three months.

As additional current data becomes available, a statistical analysis of the current requirements for the individual hulls will be made to determine if CP adds to the protective life of the paint by decreasing flaking or undercutting. In addition some insight should be obtained toward the possible use of current data in estimating the paint condition of a painted hull.

Current requirements for the YR-46, YR-50, and the AFDL-12 are presently about 22, 40, and 10 amperes respectively. It should be noted that the current for the AFDL-12 has increased only about 2 amperes during the four years under CP. Generally, protection can be maintained with a current density of five milli-amperes per square foot for unpainted steel; therefore, the additional two amperes would indicate an increase in exposed area of 400 sq ft or 100 sq ft/yr. The drydock was reconditioned in Spetember 1948, and when protection was installed in 1950, the hull required about 8 amperes for protection. Experience with the AFDB-4 indicates the hull would have required about 1.5 amperes immediately after reconditioning due to paint imperfections; thus, in the two years before protection the increase in exposed area was about 1300 sq ft or 650 sq ft/yr. This would indicate a reduction in exposed steel due to paint deterioration by a factor of 6, if a linear rate of paint deterioration is assumed. A possible discrepancy exists in applying these calculations to a hull painted with Formula 15 HP because the normal antifouling properties of this coating are dependent upon slow deterioration of the coating to expose fresh layers of toxic material. The normal expected antifouling life of this paint is about 2 years, which would suggest the coating deteriorates at a higher rate during the first two years. A complete inspection of this hull is planned during the next scheduled drydocking in May 1955.

Figure 5 shows the typical range of polarization potentials of the various hulls with respect to a $Cu/CuSO_4$ half-cell. The variation between port and starboard values is attributed to the condition of the paint on that particular portion of the hull or to improper current distribution. The current density in the region of the AFDL-12 is uneven due to the large current requirements of the two YR's. Anode current measurements indicate that approximately half of the current supplied to these hulls comes from anodes located under the AFDB-4 Sections even though two 4" dia x 80" anodes were added in the vicinity of the YR's.

The major portion of the Long Beach System has been in continuous operation for approximately 2½ years, and, as might be expected, maintenance of the system has increased during the past year. Two inspections of the complete electrical system were made during 1954. The March inspection revealed cable deterioration had occurred in three places in which current leaks and subsequent corrosion of the copper had occurred. Another inspection performed in November 1954 revealed four more areas of cable deterioration. In one instance the cable was completely severed, and two anodes were lost. The deterioration occurred in five of the instances within 15 feet from shore, which indicates that this area may require additional protection for the cable. The shore embankment is composed of large, sharp-edged rocks which occasionally roll down and in so doing may have ruptured the cable insulation. The anode lead cable is neoprene insulated #4AWG stranded cable and visually appears to be in good condition. In Figure 6 a typical leak was detected by visual signs of copper salts, and the insulation was stripped back to show the corrosion of the copper.

The graphite anodes originally installed in May 1952 are showing some deterioration. During the March inspection one anode was found to be completely severed from its lead due to moisture intrusion at the connection. The November inspection revealed several more instances where the neoprene washer seal had hardened and cracked, endangering the life of the anode lead connection. An example of this type failure is shown in Figure 7. The two 4"x80" anodes added to the system utilize an improved type connector in which a graphite washer supplements the neoprene, and the lead wire is soldered into a threaded metal connector permitting increased stress on the lead cable. While this improvement should extend the life of the anode, the greatest deterioration of the graphite is at the ends due to the preferential discharge of current from a sharp edge rather than an extended surface. Figure 7 also illustrates the extent of this deterioration on an anode which has been in service approximately 2½ years. Currents ranging from 3 to 10 amperes have been impressed through the anodes. It is recognized that 10 amperes exceed the safe limit of this size anode, and precautions are being taken not to exceed the recommended 1 ampere per square foot of anode surface. Possibly, an optimum anode design should either incorporate protection for the whole end of the anode where the lead is attached, or the shape of the anode should be changed to permit attachment in a central portion of the anode.

The additional problem associated with using an anode bed on a harbor bottom exists when mud or silt reduces the effective area of the anode and causes abnormal deterioration in particular areas. Figure 8 is a support constructed of bakelite which has been in use for eight months with a 4"x80" anode. The anode appears in excellent condition, and no deleterious effect on the support is visible. The large area on the bottom of the support keeps the anode from sinking into the silt, and a piece of electric cable attached to the support and to the lead wire junction permits raising and lowering the anode with the lead cable, releiving some of the stress on the anode lead connection.

The coupon, photographic, and mold methods of measuring and recording the effectiveness of CP on the AFDB-4 (except Section F which was docked without notification of project personnel) were completed in September 1954. The coupon program consisted of edge welding eight preweighed, mild steel, one-square foot coupons between the skegs at various depths below the water line. One set of four was painted, and the other four unpainted. The coupons on Section A were further modified by mounting four of the coupons on bakelite strips to provide comparative data on unprotected coupons. It is anticipated these coupons will remain on the hulls until the next drydocking; however, if for any reason the program is altered before that time, the coupons can be removed by a diver. Additional boxes, called "portable plates," fabricated of mild steel, approximately 20 inches square and extending 2 inches from the hull, were welded to the hull amidships, 4 feet below the water line. The boxes contained plugs at the top and bottom for filling with preservative to insure no corrosion occurred on the inside surface. Two of these test boxes were attached to each hull; one box was painted, and the other remained unpainted for comparison. The boxes are used to simulate the hull conditions as much as possible by using rounded corners and no projecting edges; however, removal of the plates for inspection and recording purposes is possible.

A means of permanently recording the physical condition of the hull in selected areas before and after periods of protection to determine the effects of CP in existing pits and the possible formation of new pits has been attempted by making an impression mold. The mold is made with hydrostone (a fine grade of gypsum cement) with dimensions of 12"x9"x1". The hull area is carefully sandblasted, marked with metal punches for identification, and coated with a thin film of light oil to prevent the hydrostone from sticking. The hydrostone is thoroughly mixed with sufficient water to make a thick slurry and then poured into a wooden mold. The slurry is repeatedly troweled to work as much of the air out as possible and to present a smooth surface. The mold is then placed against the hull in the desired location and allowed to stand for approximately 45 minutes before removing. Figure 9 shows a mold in position with two 100 lb pull, permanent magnets firmly anchoring it to the hull. Six or eight such impressions were taken of each hull. One area was selected for both bow and stern and two or three on each side amidships, depending upon the available time. The amidship positions were usually taken at the waterline, approximately 4 feet below the waterline and on the bottom. The areas were carefully located as to the distance from welded seams, draft numbers, or other identifying marks on the hull. This information will be used when similar molds are taken at the next drydocking. In addition, the areas were photographed in both black-and-white and color to further facilitate identification and depth of pits. Figure 10a is a typical photograph of a selected area compared with Figure 10b, a reverse picture of the mold of the same area. The small holes appearing in the mold photograph are due to air bubbles trapped during hardening of the hydrostone.

AFDL-20

The difficulty in maintaining a steady polarization value on an operating drydock was pointed out in Reference 4. The addition of rheostats and control boxes in the anode leads simplified the method of current control and permitted a finer adjustment of control than removal of the anodes as previously performed. The range of polarization values shown in Figure 11 illustrates the irregularity of values even with the large range of currents utilized as shown in Figure 12. Again several factors inherent in a discrete control system contributed to the variations from the desired 850 millivolt value. Each change in draft level for operating or maintenance purposes of the drydock requires almost continual manual monitoring and current adjustment until current and polarization reaches equilibrium values. This type of operation is not economically feasible; consequently, a compromise of adjusting the current to a value which would limit the polarization to a maximum of 900 millivolts at minimum draft levels was established. Such a procedure is not conducive to optimum protection; however, it does minimize the possibility of damaging the paint system. The abnormal deterioration of the paint in the 5-foot to 8-foot draft level also contributed to the large number of current adjustments necessary because of the relatively large change in exposed metal with small changes in draft level. A more detailed discussion of the paint deterioration was reported in Reference 5.

In August 1954 two additional 51-lb magnesium anodes were installed with resistance control to provide sufficient current. These anodes were added on alternate corners of the hull from the two existing anodes to improve the current distribution. Figure 13 shows a control box which houses a 5-ampere shunt and a 25-watt rheostat. The present system enables the surface polarization around the hull to be maintained within a range of 30 millivolts as shown in Table 1.

Of the various coatings and sealers tested to restrict the magnesium deterioration in the vicinity of the pipe core extending through the center of the anode, two adhesives* have shown promise.

*Pliobond #30 thermoplastic adhesive - Goodyear Tire & Rubber Co.,Inc.
EC -711 Synthetic rubber adhesive --- Minnesota Mining & Mfg. Co.

A comparison between a coated and uncoated anode is shown in Figure 14a and 14b. The protected anode shown has been in service about four months, and the coating has retarded the formation of magnesium hydroxide; however, as the body of the anode continues to deteriorate, it is doubtful if the coating will remain intact due to undercutting - hence, some maintenance of the coating is expected. The possibility that the expense of coating and maintenance of the coating may exceed the benefit of more efficient anode use should be investigated further and may indicate a modification of the anode core is desirable.

AUTOMATIC CONTROL

Laboratory CP investigations with an operating drydock or semipermanent multiple hull system have continually emphasized the need for maintaining close control of protection currents and associated potentials. To maintain those potentials at an optimum level, close surveillance by competently trained personnel has been found necessary. The development of a continuous monitoring and control system for use in a ground installation has been reported in Reference 6; however, no work of this type has been done in a sea water installation to the author's knowledge. The difficulty of such a system lies principally in the magnitude of the potential and difficulty of continually measuring the potential in question. The standard detecting element, copper-copper sulfate half cell, used for short periods (seldom over several hours if continuously submerged) provides a reliable, easily prepared reference; however, contamination of the sulfate solution by chloride ion from the sea water and eventual coating of the copper by copper chloride results in a change in potential characteristics of the cell. The use of special hardwood porous plugs have lengthened the useful life of these cells, but contamination is still experienced in a matter of days. A further modification in the form of a compartmental cell where the rate of contamination is retarded by passage of the ions through one or more compartments of sulfate solution has been successfully used for periods of several weeks. A porous plug of hydrostone was substituted for the standard wood plug; however, gradual softening and subsequent deterioration of the plug occurred. Various cement mixtures have been tried as porous plugs with little success due either to alteration of the potential or excessive resistance of the plug. Tests of other commerically available or laboratory prepared half cells and electrodes shown in Figures 15 and 16 have met with varying degrees of success. These elements have been tested in conjunction with an electronic servo system. Table 2 is a resume of the results of these tests. Elements being considered for further investigation are silver-silver chloride, compartmented copper-copper sulfate and electrode types of magnesium and zinc.

The amplifier and servo system as shown in Figure 17 have proven to be a compact, efficient unit and have required no maintenance in six months of operation. Initial installation of an electronic system rather than a complete magnetic amplifier type system, which would have inherently longer life, was made primarily for economic reasons. There are no complete magnetic amplifier-type systems commercially available, and the development of a unit would have to be made at considerable expense. The electronic equipment was installed at a cost of approximately $200.00, with negligible modification of the power supply equipment. The limitations of the available signal power (order of 10^{-9} watts) is within the range of the input characteristics of electronic amplifiers. Magnetic amplifiers capable of operating at such a low signal power are still in the development stage.

The control system operates by regulating the rectifier current output for a specified value of hull potential as measured with a reference half cell. The signal to the amplifier is determined by the measuring circuit consisting of the half cell located in the water, a reference voltage circuit as shown in Figure 18, and a ground lead from the protected surface. The reference voltage is set at the desired level (850 millivolts for a $Cu/CuSO_4$ cell), and any error voltage between the reference and the measured half cell voltage due to hull polarization produces a signal which is amplified, causing the servo motor to rotate the rectifier variac so that the CP current is altered sufficiently to reduce the error voltage to zero. AC pickup by the half cell is minimized by the resistance capacitance filter as shown. The inherent slow response of polarization with current change (up to 15 minutes, depending upon the magnitude of the change) necessitates the use of stops on the servo control to limit the maximum current to a safe value. The amount of control would vary depending upon the installation and would determine what current limit would be necessary. In the installation described, a positive mechanical stop is employed which limits the servo drive pinion to one revolution allowing a current range of 30% of the total current. The control mechanism is set with the current adjusted to the approximate correct value midpoint between the stops, allowing sufficient current control for minor changes in the system. Some difficulty has been experienced in setting and maintaining the reference voltage when the system is considerably out of balance. A new reference voltage circuit with possible inclusion of a standardization feature is planned.

EVALUATION OF PAINTED COATINGS IN CONJUNCTION WITH CP

The Bureau of Yards and Docks has expressed considerable concern as to the effect of CP on standard Navy shipbottom paints. An experimental study was reported in Reference 2 on several coatings; however, the results were of a preliminary nature, and a more detailed investigation was recommended. Additional studies of this type have been reported in the literature with various objectives and results obtained. A review of these studies and subsequent Bureau inquiries pertaining to the compatibility of CP and coatings have resulted in a program designed to evaluate selected coatings under field test conditions. An attempt has been made to choose test panels sufficiently large enough to enable evaluation of the coatings in the splash, waterline, and underwater zones and requiring currents great enough to be easily measured and accurately controlled but panels small enough to be handled by one man for inspection purposes. A size of 6 feet in length by 4 inches wide and $\frac{1}{4}$ inch thick met these requirements, with approximately 5 feet of the panel being submerged. A circular type floating suspension for the panels was designed to permit mounting of a 3"x60" graphite anode in the center as shown in Figure 19. The symmetry of the design insures even current distribution over the entire length of the panel. The panel is rigidly bolted to an insulating block which is bolted to the metal ring support; consequently, each panel is electrically insulated to facilitate control and measurement of the individual current requirements. The original control panel as shown in Figure 20 was modified by the addition of another meter and jacks to provide for measuring a larger range of currents. A schematic of the modified panel is shown in Figure 21.

The panels were fabricated from mild steel plate (SAE1020) and were carefully sandblasted immediately before coating. The selection of coatings was based upon Bureau recommendations of standard coatings presently in use on underwater structures and coatings showing the most promise in existing Laboratory sea water immersion tests. The initial test is to determine the compatibility of the particular coating applied, using specifications supplied by the manufacturer or the Navy, with CP potentials generally used. An optimum potential level of 850 millivolts is desired, as measured by a $Cu/CuSO_4$ half cell with a tolerance of approximately ± 50 millivolts. The coatings under test at present are listed in Table 3, and it is anticipated that additional panels will be installed as promising materials become available. As shown in the table, some of the coatings are zinc pigmented, and two panels were zinc and aluminum wire sprayed for comparative data. These self-protecting panels will not be electrically connected into the protective circuit except in the case of the zinc pigmented coatings when a potential of 750 millivolts can no longer be maintained naturally.

Each coating has been scribed on one side in an accepted manner to accelerate undercutting or flaking effects. Inspections of the panels will be made every three months, and they will be rated on a basis of blistering, flaking, undercutting, type and amount of fouling, and amount of current required for protection. The length of the test will be determined by failure of the coatings or until such a time that an estimated life expectancy of the coating can be made. Significant developments of the test will be made available to the Bureau through the regular monthly progress reports, and a final detailed report covering the test will be made upon completion.

PROPOSED EVALUATION OF FLOAT COATINGS IN CONJUNCTION WITH CP

The protection of the interior compartment surfaces of floating drydocks has been a continuous problem for the Bureau of Yards and Docks. Until recently protection has been achieved primarily with the use of painted coatings, which has proved to be both costly and, in many instances, inadequate. In recent years the use of floatation-type coatings and CP in individual installations have shown promise of providing continuous protection with a minimum of maintenance. Inherent limitations associated with each method do not always permit optimum protection of all areas of the compartments. In the case of CP alone, the area submerged can be protected, but the intermittent filling and de-watering of the compartments is conducive to periods of under- or over-protection. The use of a floatation-type coating does not always permit protection of areas in which some residual water remains upon de-watering the tank. For these reasons a study of the compatibility of the two methods in a field test simulating actual drydock operations is planned. The test is to be conducted in T6B-type pontoons which are readily available and adaptable for a controlled test.

A laboratory test as shown in Figure 22 was set up in September 1954 to obtain preliminary information relative to the compatibility of CP and float coatings. No attempt was made to obtain quantitative corrosion data on such a small scale; however, current measurements and visual observations were made as the test progressed. The test consisted of graphite and magnesium (Mg) CP systems, with and without float coatings, and individual mild steel coupons approximately 4"x8". A reduction in current requirements of about 5 to 1 for the graphite system and about 8 to 1 for the magnesium system were indicated for unpainted coupons. The difference between the graphite and the Mg apparently was due to the increase in Mg ions from anode deterioration since the same electrolyte was used throughout the test. The electrolyte in the Mg test became more alkaline, and a detectable calcareous deposit formed on the coupon which aided the adherence of the float coating to the coupon. No calcareous coating was formed on the graphite test coupon. No appreciable change in the float coating was visible in the graphite system. An increase in viscosity in the Mg test was due in part to the bubbling of gas formed around the anode and possibly to some interaction between the Mg ions and the float coating. This condition would not be as prevalent with a periodic change in electrolyte as experienced in drydock compartments. Coating of the anodes with float coating did not cause any permanent effect on the efficiency of the anodes; however, with a gelling-type float coating further investigation is warranted. Commercially available products can generally be classified into two groups. Type One consists of products which gel into a semi-solid coating and permanently adhere to the metal surface. In some cases the gelling occurs gradually, and a continuous film of the material is kept on the water surface. This type is usually a two-package material composed of the inhibitor and a diluent which is added to control the viscosity of the floating material. Type Two materials do not gel appreciably, and protection is achieved primarily through continual recoating of the metal surfaces as the water level changes. This material is obtainable as a one-component preservative. To evaluate the characteristics of both types, a test facility of six pontoons is proposed. Pontoon #1 will have CP only; pontoons #2 and #3 will have float coatings characteristic of Group One and Group Two respectively, only; pontoons #4 and #5 will have float coatings characteristic of Group One and Group Two respectively, plus graphite type CP systems; and pontoon #6 will have float coating Type Two, plus a magnesium type CP system.

A measurement of the effectiveness of the various methods will be determined by the use of pre-weighed test coupons mounted in each of the three zones - wet, alternate wet and dry, and dry - of the pontoons. Observations and data as to effectiveness, current requirements, chemical or physical changes of the float coating and the effect of float coating on anode efficiency and installation components will be obtained.

The test facility will be located at Port Hueneme, using harbor sea water. Cycling periods and rates will be as close as possible to normal drydock operation values. The length of the test will be dependent somewhat upon the results of periodic inspections; however, it is anticipated approximately one year will be required to determine any interaction of the two systems. Significant developments of the test will be reported in the Monthly Progress Reports, and a final report will be made upon completion of the test.

CONCLUSIONS AND RECOMMENDATIONS

MULTIPLE HULL GRAPHITE ANODE SYSTEM: The installation of a control panel utilizing power rheostats and shunts in the individual ground return lines has simplified and increased the accuracy of current control for a multiple hull system. This method of control also permits the connection of all anodes to a common positive buss without individual current control whereby each anode supplies approximately the same current regardless of current requirements in the immediate vicinity of the anode. Periodic inspection of the underwater electrical system has been found necessary to detect failures in the cable insulation and anode lead connections. It is suspected that abnormal shore conditions have contributed to the failures in cable insulation. A new type anode lead connection is expected to reduce the deterioration of the lead connection seal; however, further refinements may be necessary to obtain maximum anode life. Protection of the anodes where a soft or shifting bottom condition exists appears desirable.

The advantages of using an anode bed located on the anchorage bottom, making the system independent of hull movements, are considerably reduced by the factors mentioned above. The economic requirement that CP systems be relatively maintenance-free emphasizes the need for solution of these problems or using a different current distribution method. Suspension of the anodes from the protected vessel has been used extensively and offers the advantages of easy anode removal, less immersed cable and indifference to bottom conditions. The disadvantages of removing the anodes for hull movement and the necessity for strain relief of the anode lead connection due to the increased stress are factors that would be dependent upon the type of installation.

It is recommended that studies directed toward resolving the problems inherent in these techniques be continued. An investigation of various promising anode materials should also be included.

GALVANIC TYPE ANODES: The magnesium anode system as presently used on the AFDL-20 is providing as high a degree of protection as possible with manual control without endangering the paint system. This type system is not conducive to automatic control development requiring external power because the inherent advantages of being independent of external power requirements would be lost. The replacement of magnesium with zinc anodes is considered worthy of investigation with the recent availability of high purity zinc at a competitive cost. The maximum potential that zinc is capable of producing would not appreciably exceed one volt; therefore, no resistance controls would be necessary.

AUTOMATIC CONTROL: A commercially available electronic servo system has been employed in the Long Beach CP System for six months with encouraging results. The limitation of the system has resulted from the need for a simple half cell capable of continuous use as a detecting element. Several promising cells are under investigation in conjunction with the servo system. With the development of a satisfactory cell, it is recommended that efforts be directed toward development of a magnetic amplifier controlled power supply. The measuring controlling and power supply system should meet the following major requirements: (a) Maintain the polarization within ±10 millivolts of a specific value, and (b) Operate continuously for three months without maintenance. The inherent life of a magnetic type unit would be comparable to that of a dry disc rectifier or a transformer. The advantages of providing an optimum protection level at all times and reducing the number of manual surveys should justify the additional cost of the control unit.

COATING STUDIES: The investigations of painted and floating type coatings as described will be continued and initiated, respectively, for compatibility of these materials in conjunction with CP.

TABLE 1

POLARIZATION OF THE AFDL-20 ON 1 NOVEMBER 1954

WITH FOUR 51 LB Mg ANODES

LOCATION	POLARIZATION	LOCATION	POLARIZATION
Bow	822	Stern	810
Port 30	830	Starboard 170	820
Port 100	800	Starboard 100	810
Port 170	816	Starboard 30	830

TABLE 2

VARIOUS ELECTRODES AND HALF CELLS

USED WITH AUTOMATIC CONTROL UNIT

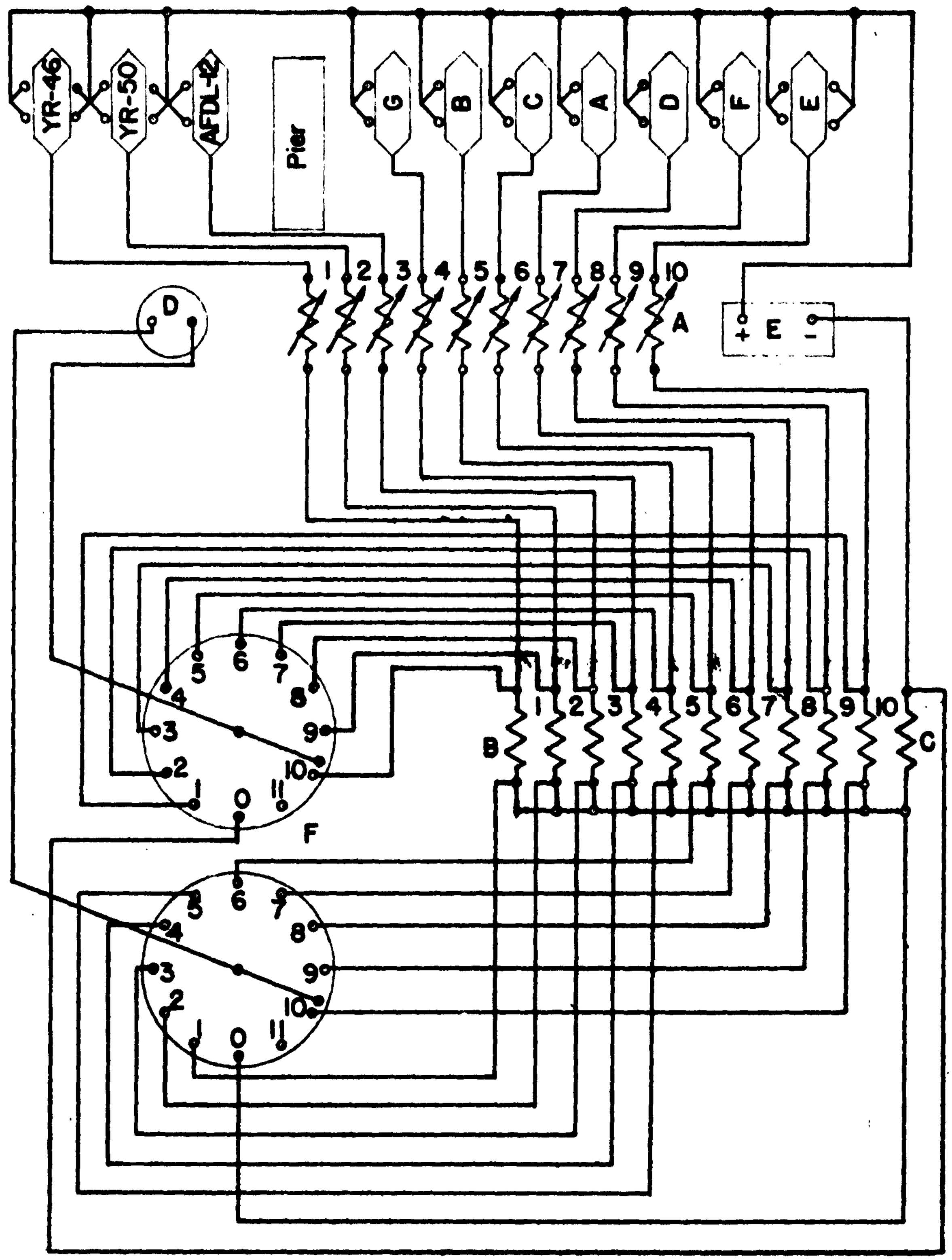
Element	Time in Service	Remarks
$Cu/CuSO_4$ with hardwood plug	4 hours	Not satisfactory, potential began to vary up to 20 mv.
Ag/AgCl Lab. constructed	7 days	Operated satisfactorily during this period
Ag/AgCl commercial	8 days	Failed apparently due to deterioration of AgCl coating
$Cu/CuSO_4$ compartmented	11 days	Operated satisfactorily except for deterioration of porous plug
Calomel commercial	6 days	Failed due to excessive loss of KCl solution
Ag/AgS commercial	$1\frac{1}{2}$ hours	Failed due to rapid polarization and resulting potential change
Sb/SbS commercial	8 days	Operated adequately, however, slight potential drift
Mg electrode Lab. constructed	6 days	Operated satisfactorily except for deterioration at lead connection end
Pt electrode commercial	14 days	Intermittent satisfactory operation dependent upon polarity and resultant polarization
C electrode Lab. constructed	14 days	Only controlled with one polarity apparently polarized when cathodic
50% Pb-50% Sn electrode Lab. constructed	26 days	Operated for approximately 20 days before oxide coating formed changing its potential
Zn electrode Lab. constructed	32 days	Operated satisfactorily except for slight drift. Surface corroded with some fouling accumulating

TABLE 3

COATINGS UNDER TEST IN CONJUNCTION WITH CATHODIC PROTECTION

Top-coat	Undercoat	Source
1. Vinylidene chloride resin BuS Form #113/49	Form #117 wash prime	Navy It. 1653 Stock No. G52-R-442
2. Vinyl Form #129 AF *	Form #117 wash prime Form #119 primer	Navy Stores Item 115 Stock No. G52-P-178-5400
3. Vinyl acrylic Lacquer	Form #117	Navy Stores It. 1898A Stock No. G52-G-2218-120
4. Form #105 AF Cold plastic	Form #117 wash prime Form #14 AC	Navy Stores It. 1127 Stock No. G52-P-6578
5. Form #145 AF Cold plastic	Form #117 wash prime Form #14AC	Navy Stores It. 1135 Stock No. G52-P-6581
6. Form #15HP-1A Hot plastic AF	Form #117 wash prime Form #14AC	Navy Stores It. 1123 Stock No. G52-P-6550
7. 34Yb coal tar Cold enamel	None	Navy Stores It. 1703 Stock No. G52-C-2098-10
8. 34Yb coal tar Hot enamel	Coal tar primer	Commercial
9. Zinc Pigment, polystyrene vehicle	None	Commercial
10. Vinyl resin	Form #117 wash	Commercial
11. Phenol resin	Phenolic primer with mica filler	Commercial
12. Epoxy resin amine catalyzed	Red lead pigmented epoxy primer	Commercial
13. Chlorinated rubber	Wash prime chlorinated rubber primer	Commercial
14. Furan resin	Red lead pigmented primer	Commercial
15. Copper pigmented Af (vehicle unknown)	Zinc chromate primer mica pigmented primer	Commercial
16. Neoprene	Chlorinated rubber primer	Commercial
17. Zn, Pb pigment inorganic vehicle	None	Commercial
18. Alkyd resin	None	Commercial
19. Zinc metal spray	Carbon steel	Commercial
20. Aluminum metal spray	Carbon steel	Commercial

* AF - antifouling



A – 300 Watt, 0.5 Ω Power Rheostats
B – 30 Ampere Line Shunts
C – 300 Ampere Output Shunt
D – 300 Ampere Ammeter
E – 300 Ampere 18 Volt Rectifier
F – Tap Switch

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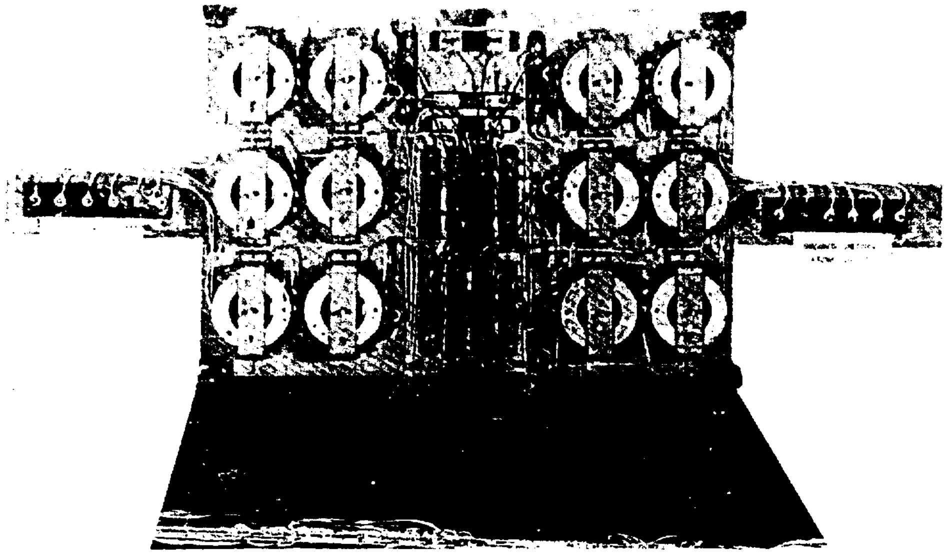
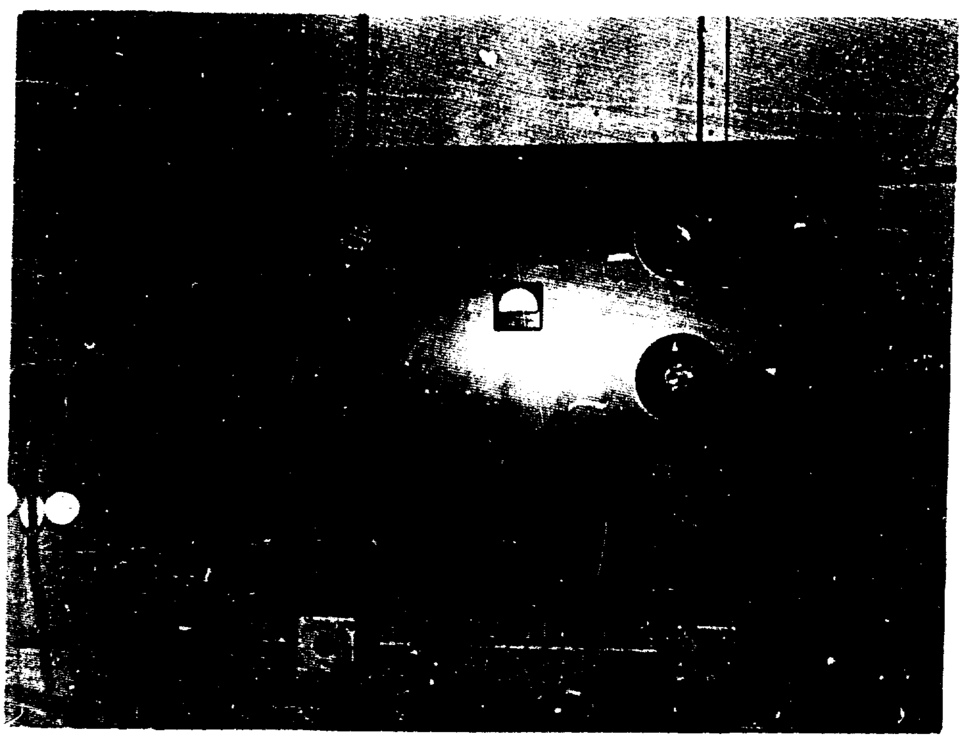
Fig. 1 LONG BEACH INSTALLATION





ure 2. Control Panel for Long Beach Cathodic Protection System.

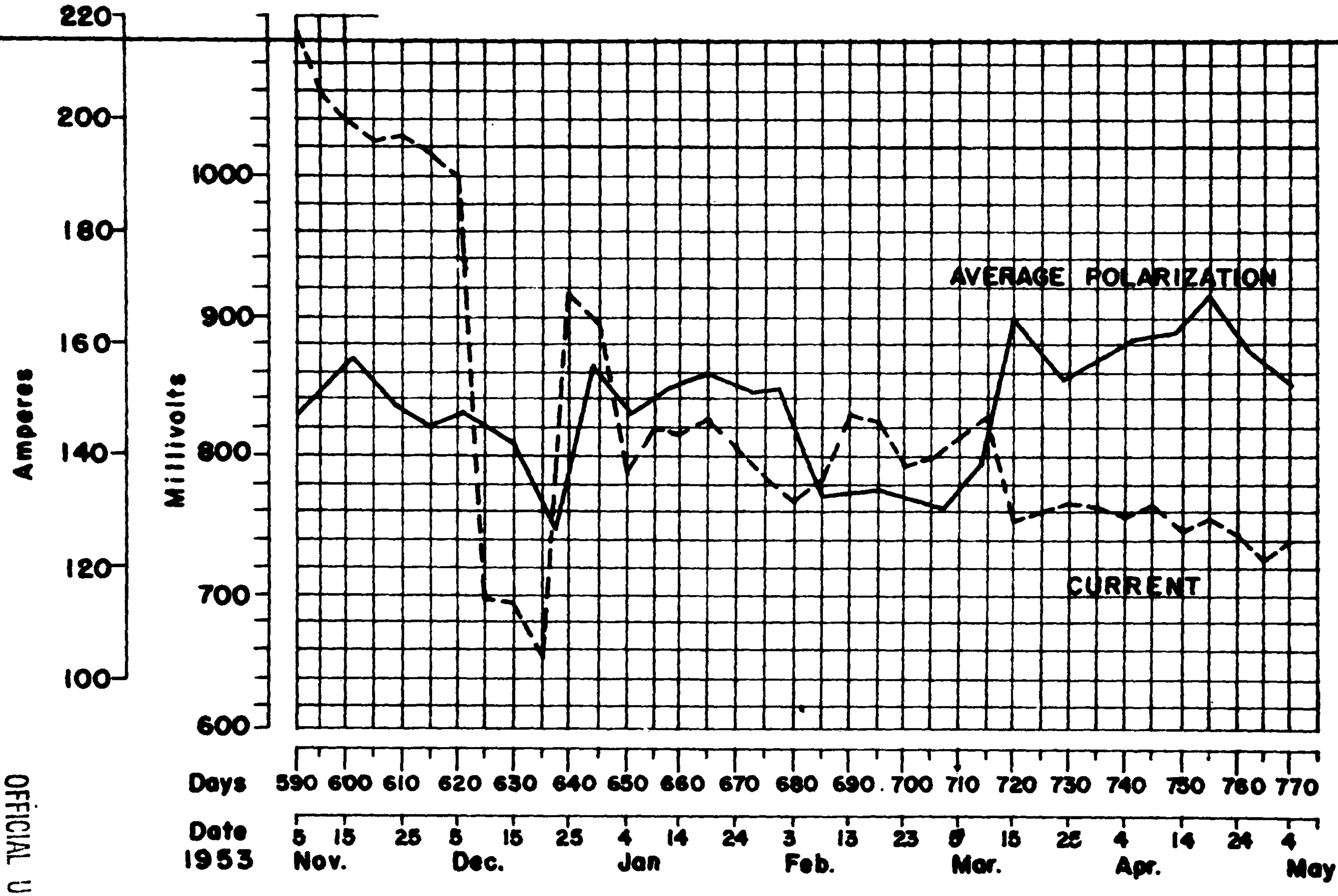


Fig. 3a CATHODIC PROTECTION RECORD, Long Beach Installation

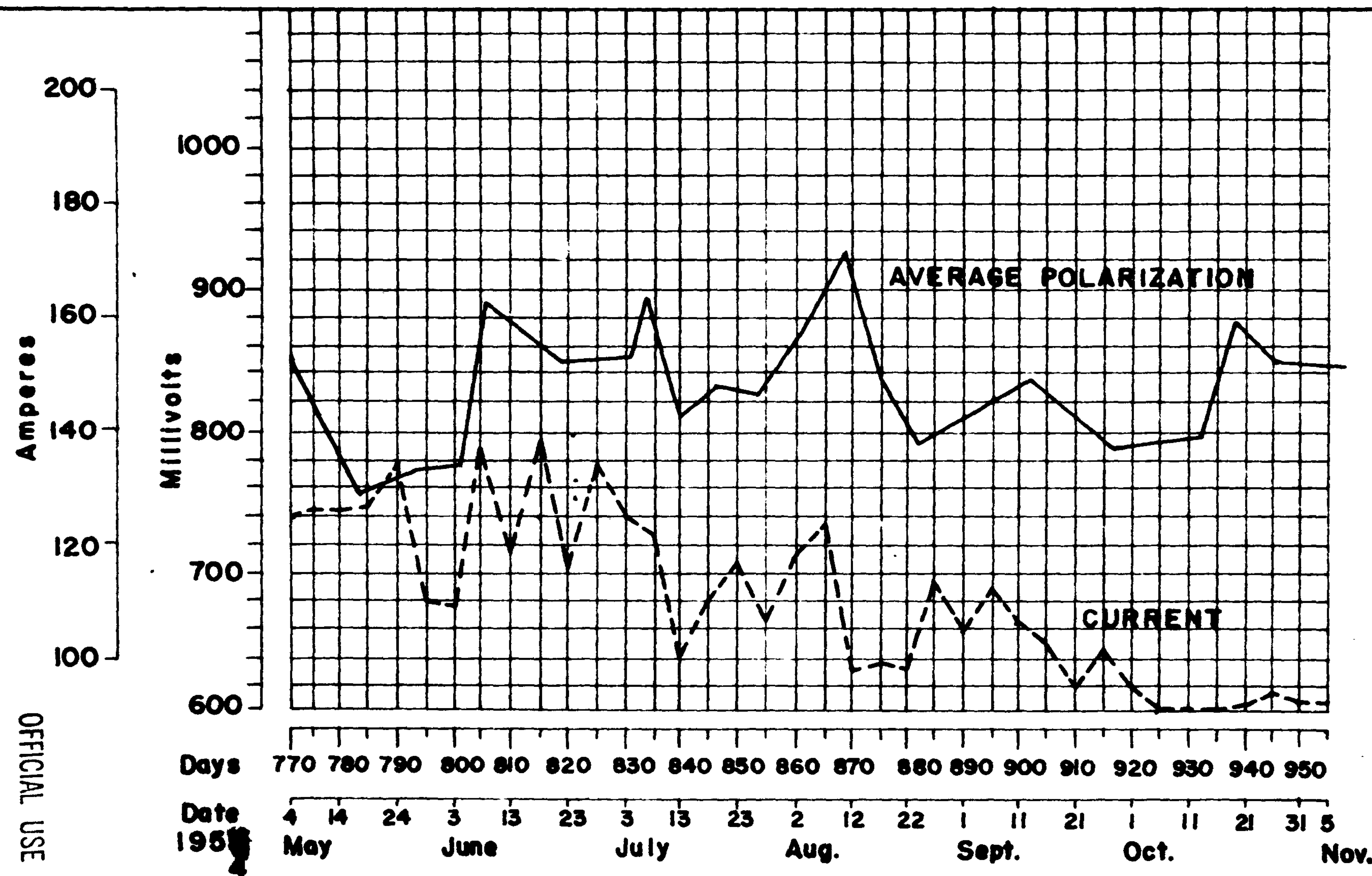


Fig. 3b CATHODIC PROTECTION RECORD, Long Beach Installation

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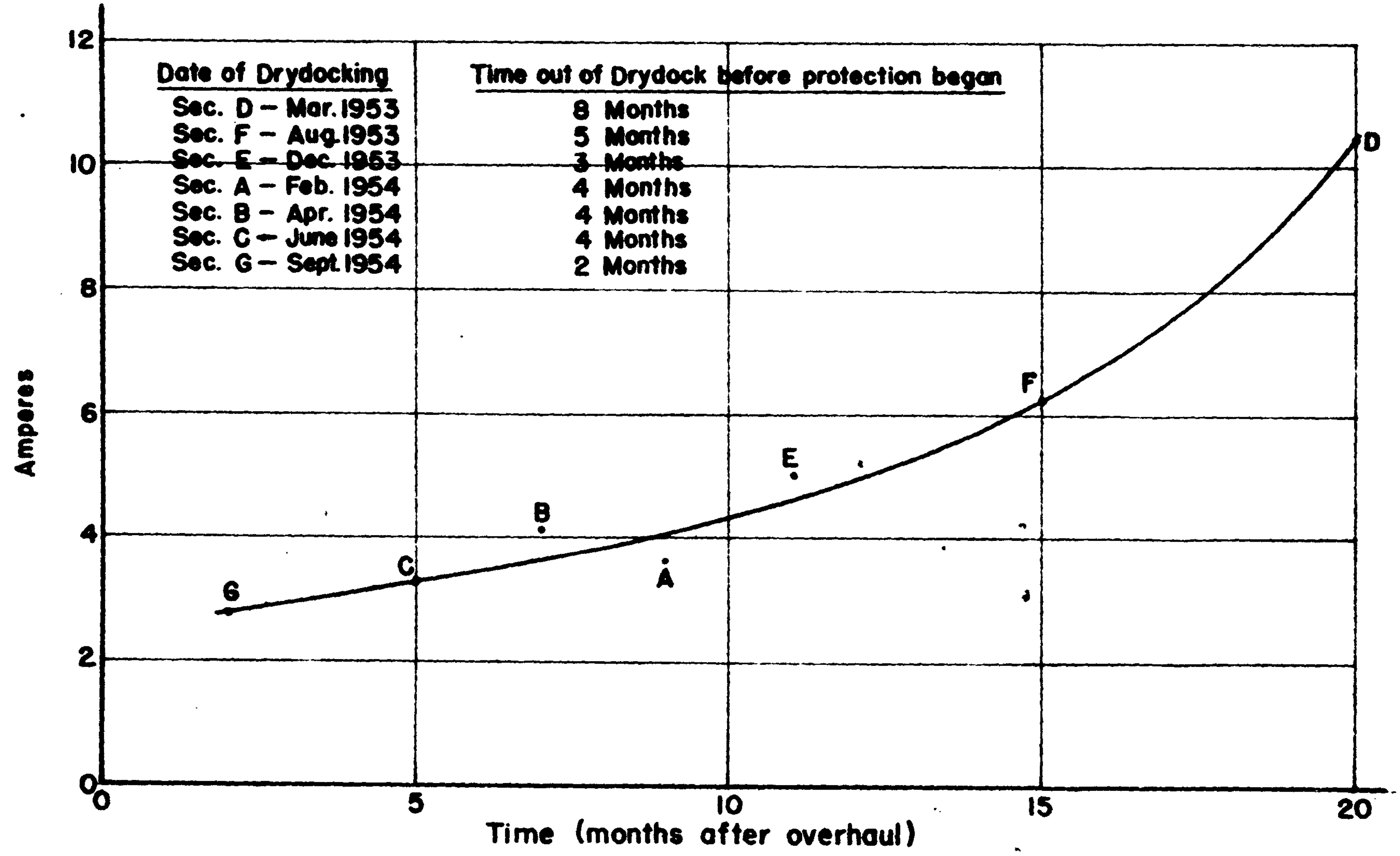

Fig. 4 CURRENT REQUIRED BY HULLS, November 1954

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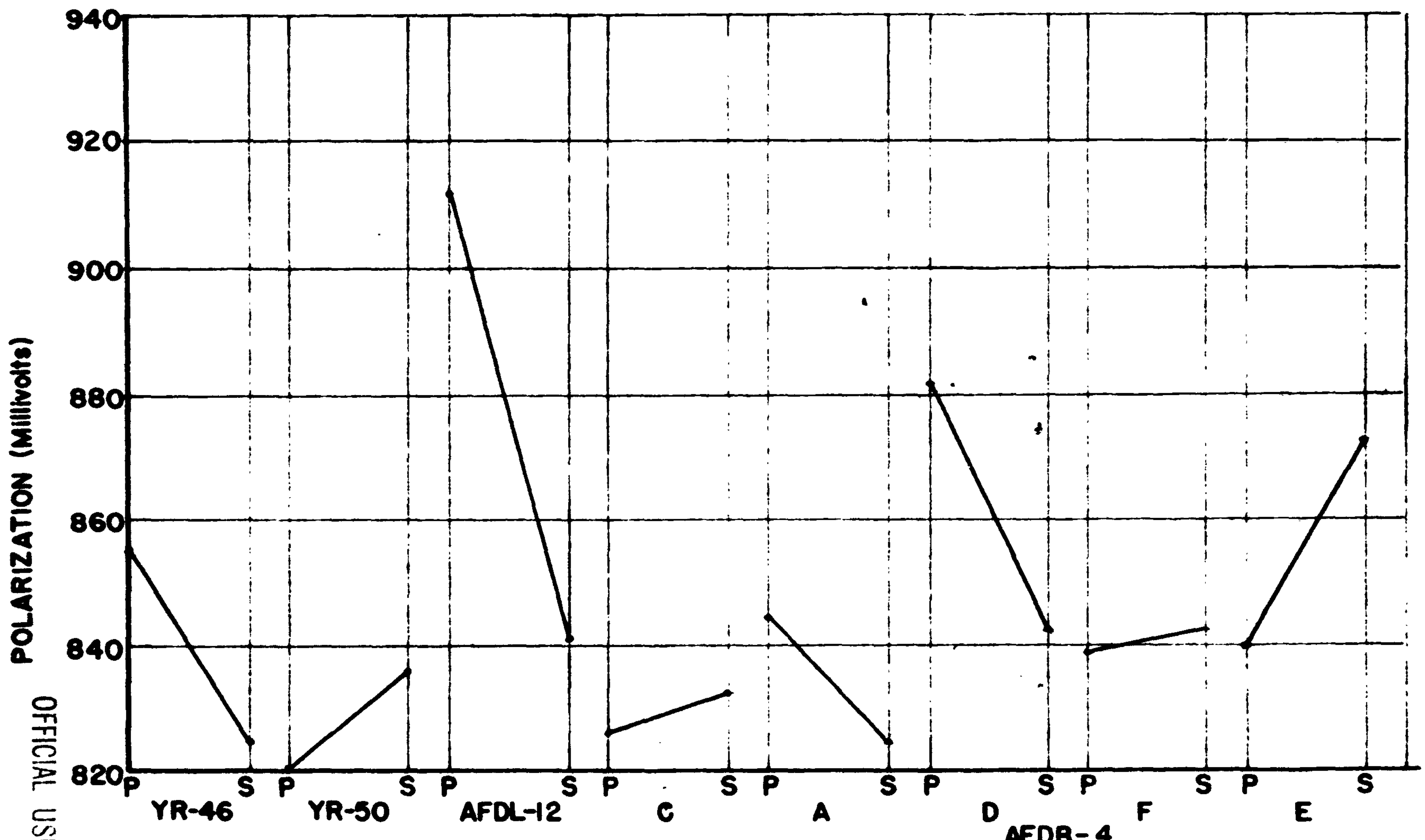

Fig. 5 SURVEY TAKEN 26 Oct. 1954 INDICATING THE RANGE OF POTENTIALS OF THE VARIOUS HULLS

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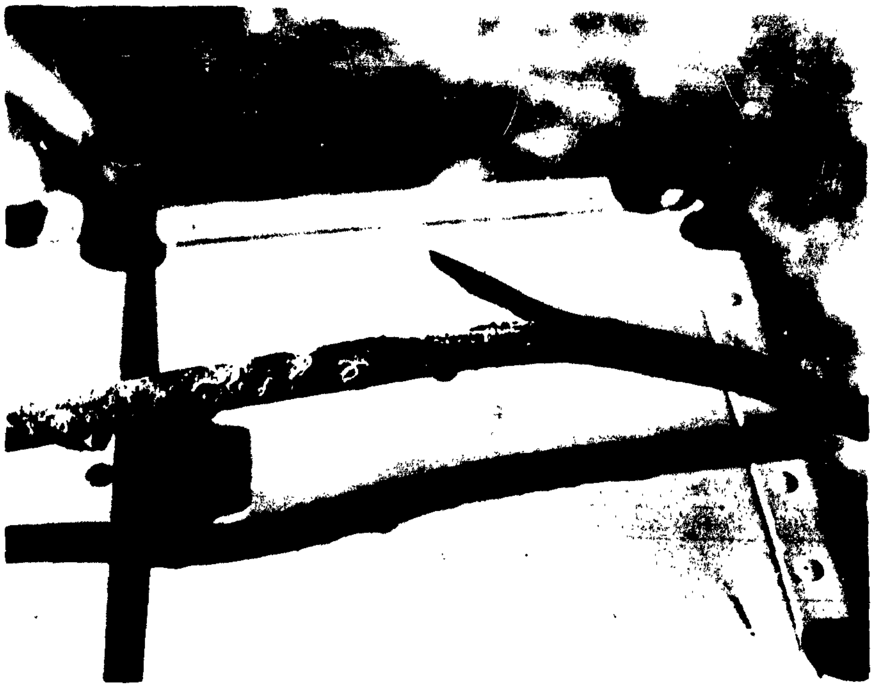

Figure 6. Example of anode lead cable deterioration.

Figure 7. Deterioration of neoprene seal at anode lead connection.

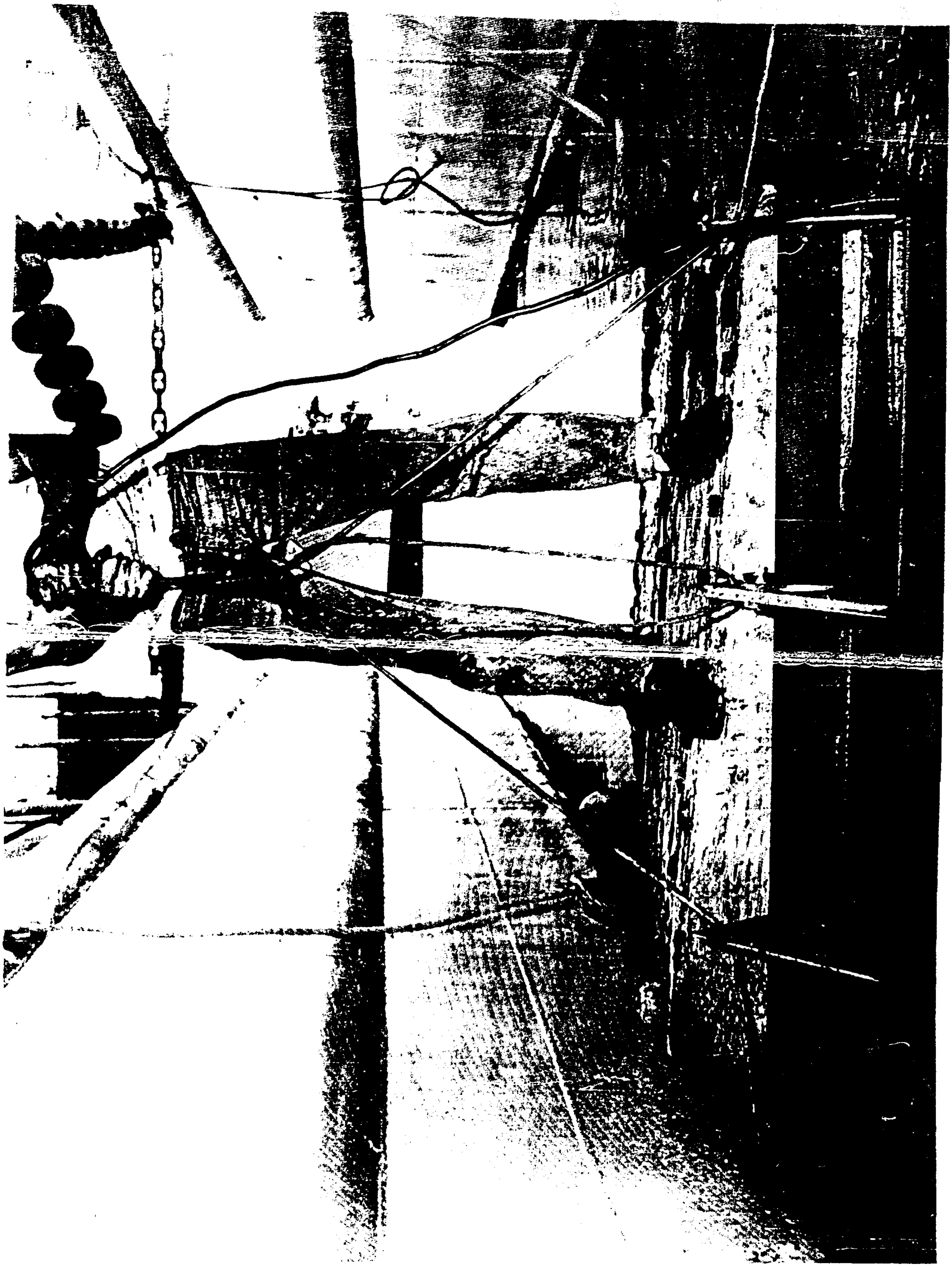

Figure 8. Bakelite support for 4" x 80" graphite anode.

Figure 9. Hydrostone mold in position on a dry-
dock hull.

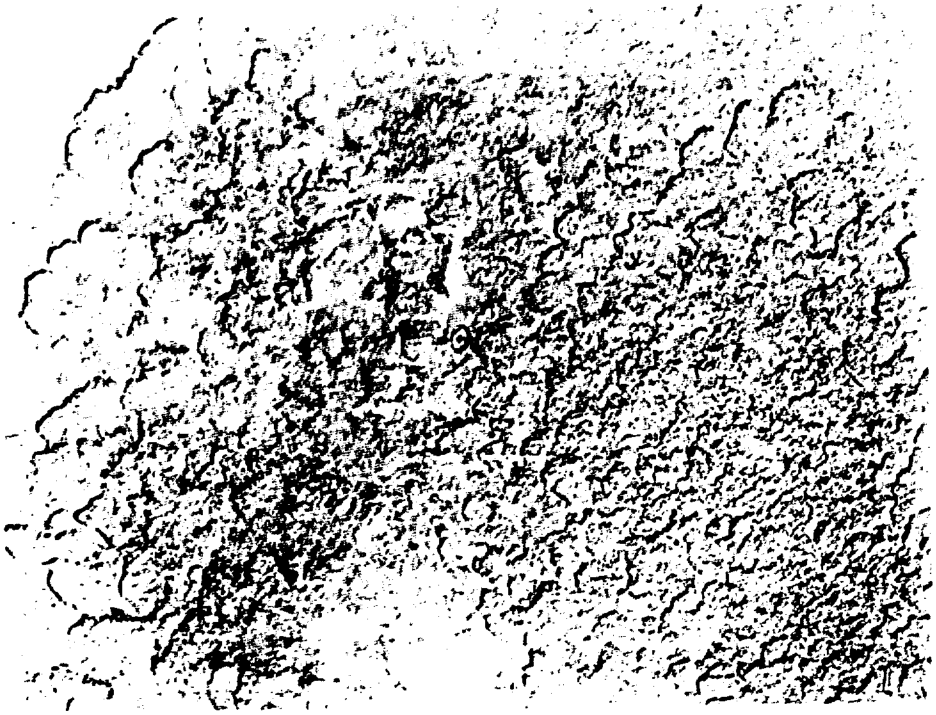

Figure 10a. Actual photograph of hull surface before mold was taken

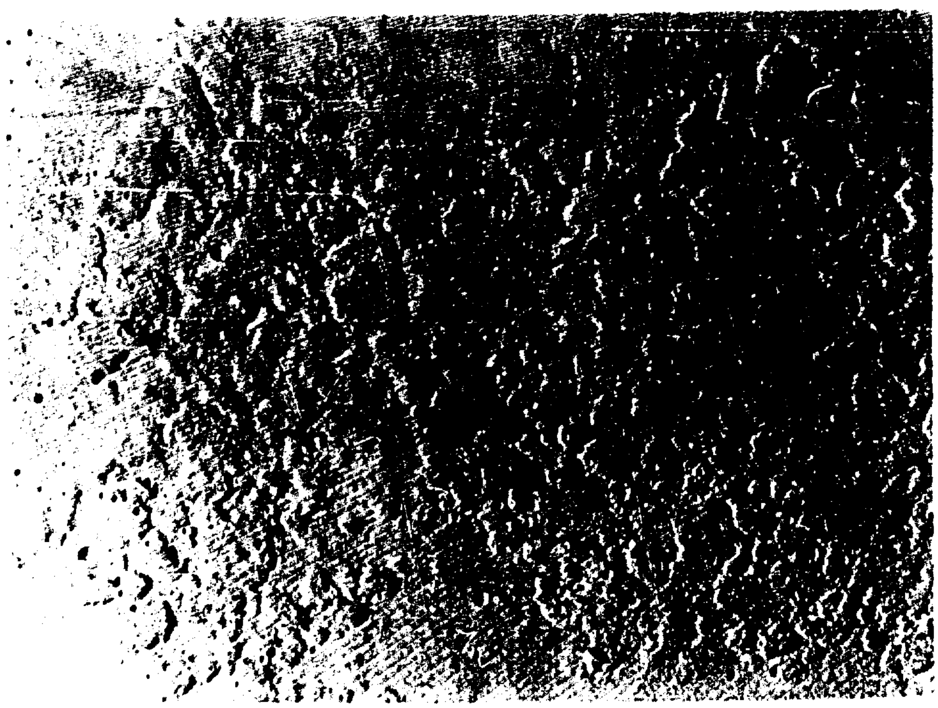

Figure 10b. Reverse photograph of hydrostone mold of same surface.

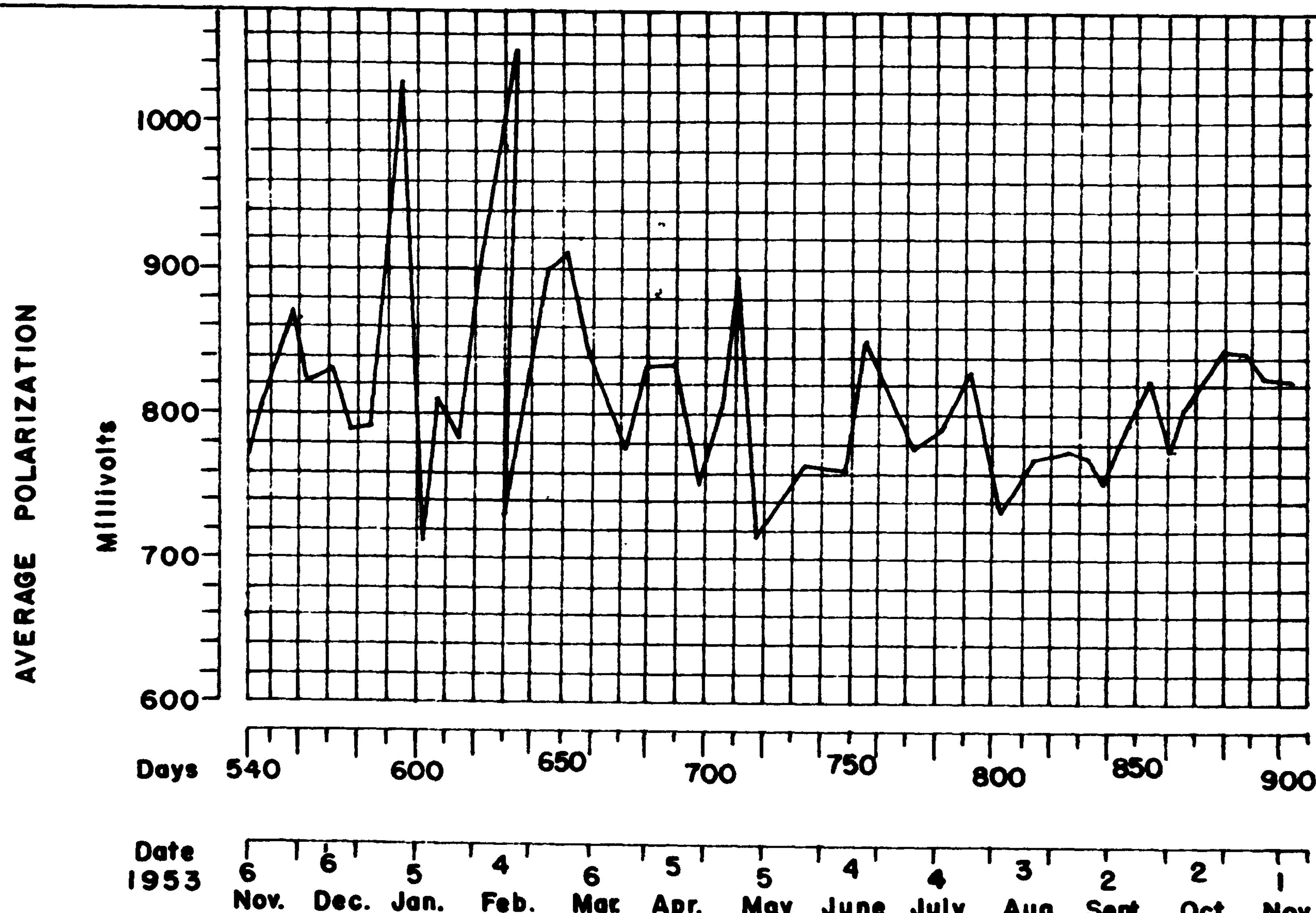

Fig. 11 POLARIZATION RECORD For AFDL-20

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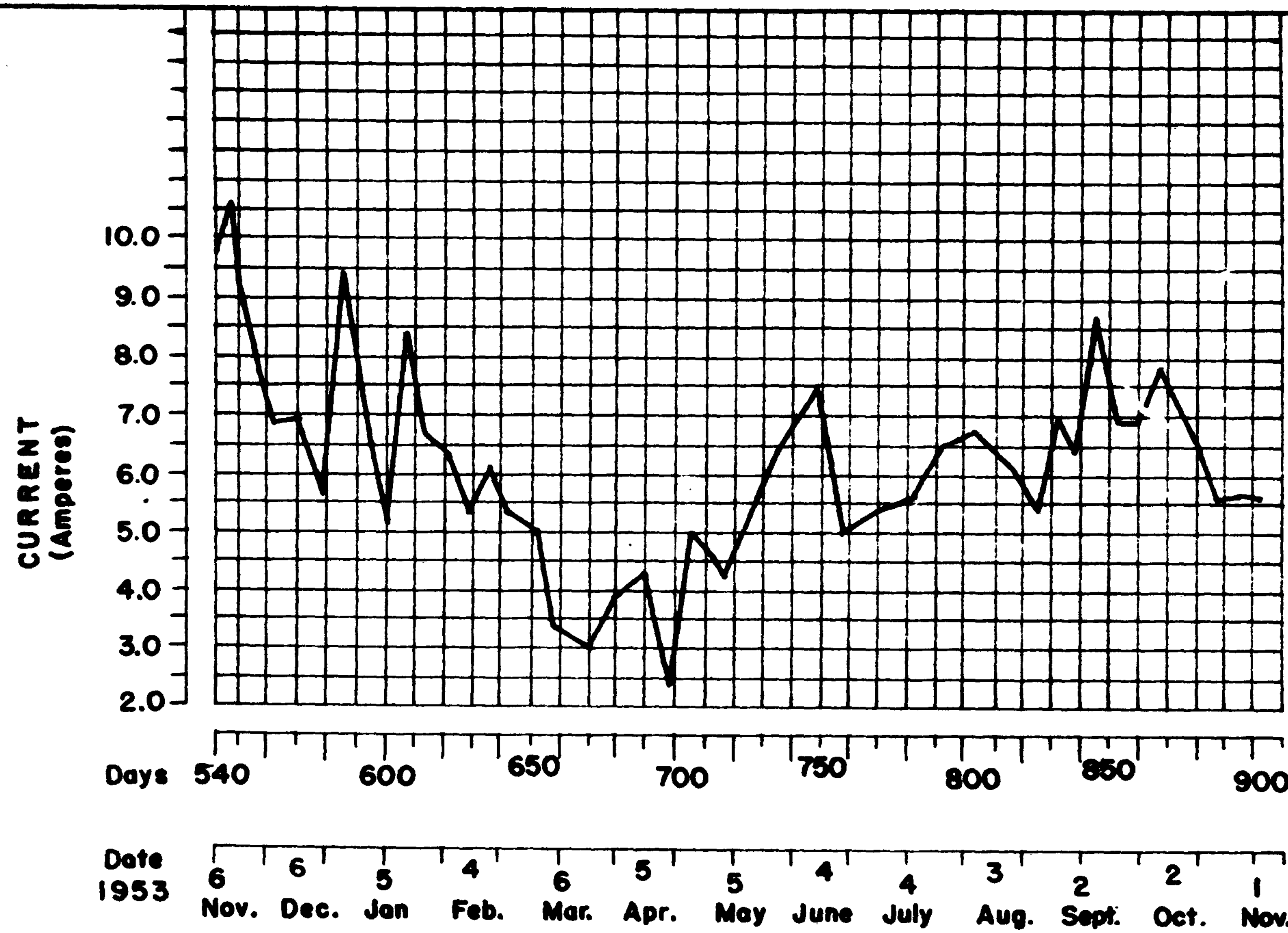

Fig. 12 CURRENT RECORD For AFDL-20

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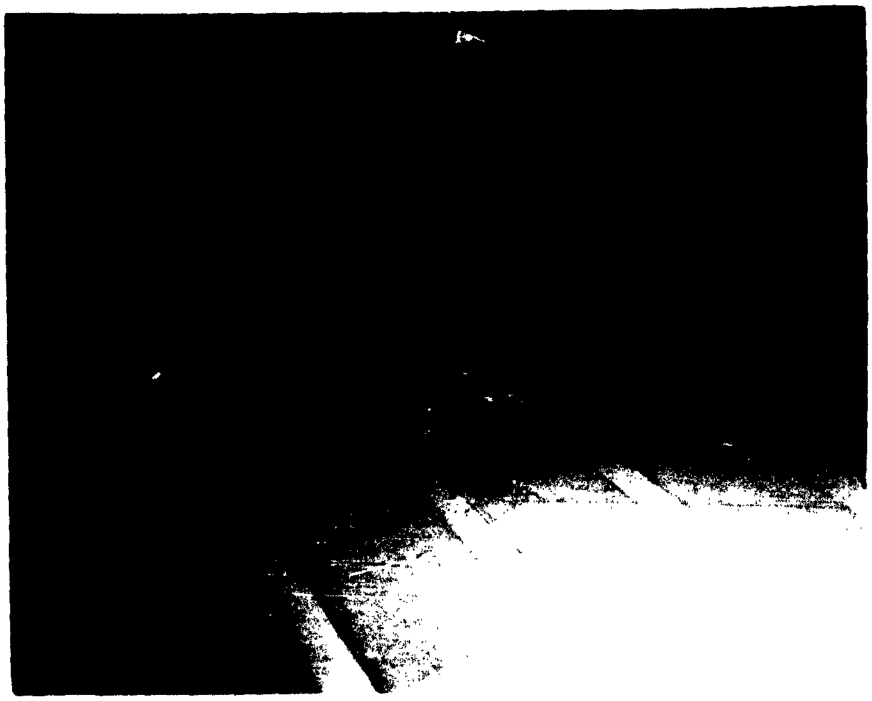


Figure 13. Control box used with magnesium anodes on the AFDL-20.

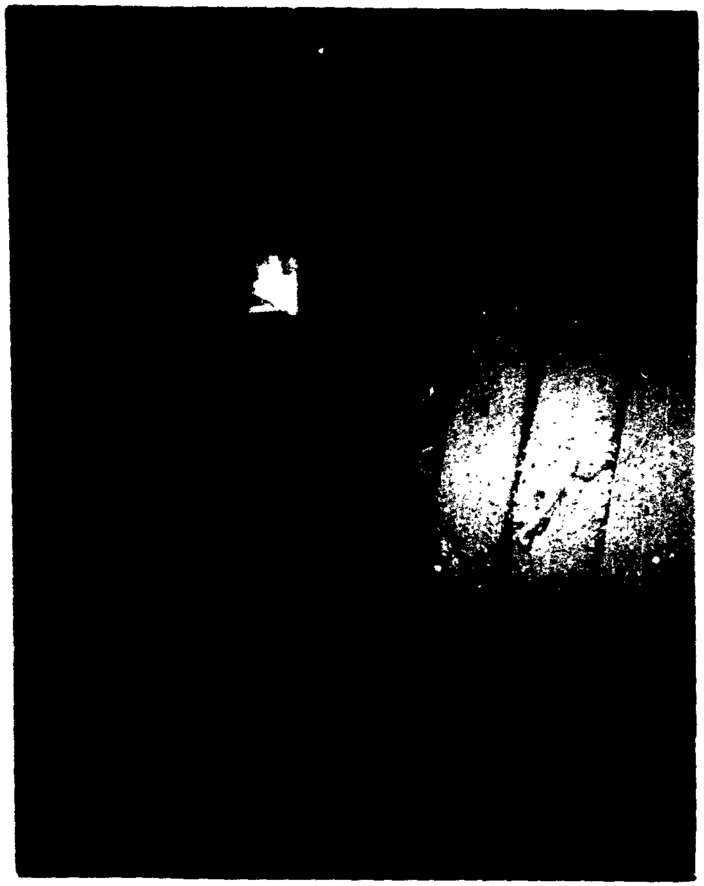


Figure 14a. Uncoated magnesium anode showing formation of magnesium hydroxide on the pipe core.

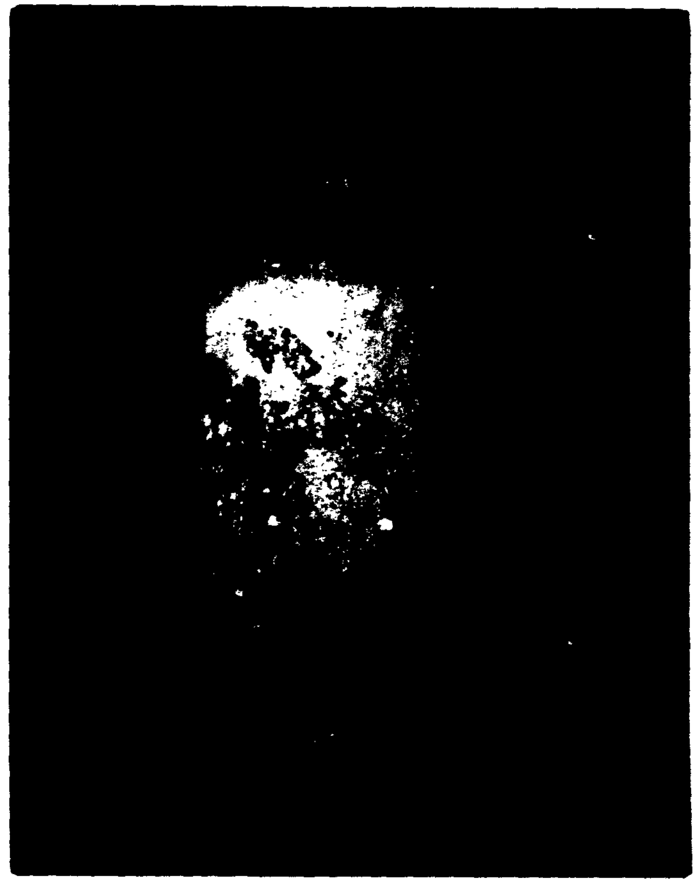
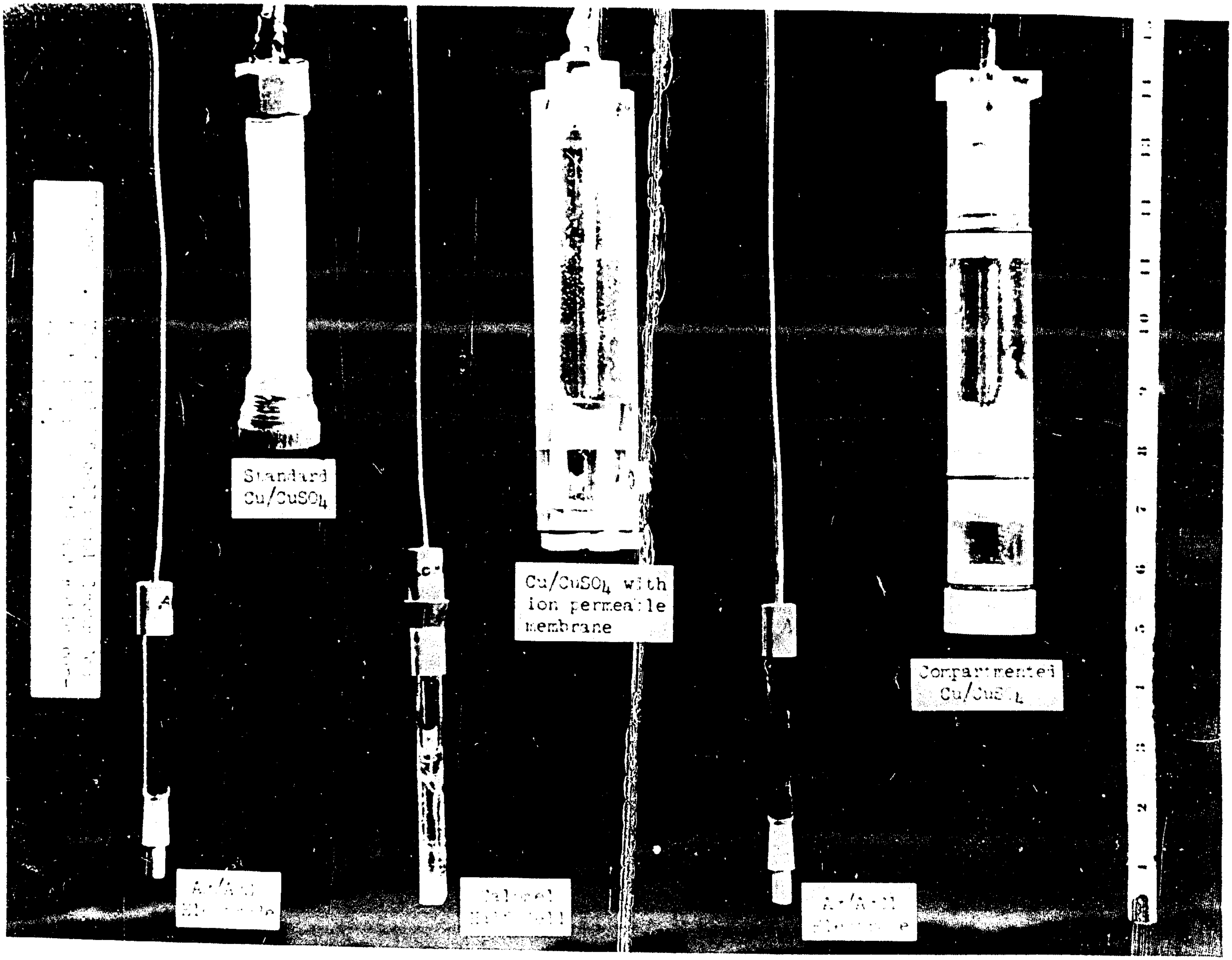


Figure 14b. Coated magnesium anode showing retardation of anode deterioration in the vicinity of the pipe core.



Standard Cu/CuSO4
Cu/CuSO4 with ion permeable membrane
Compartmented

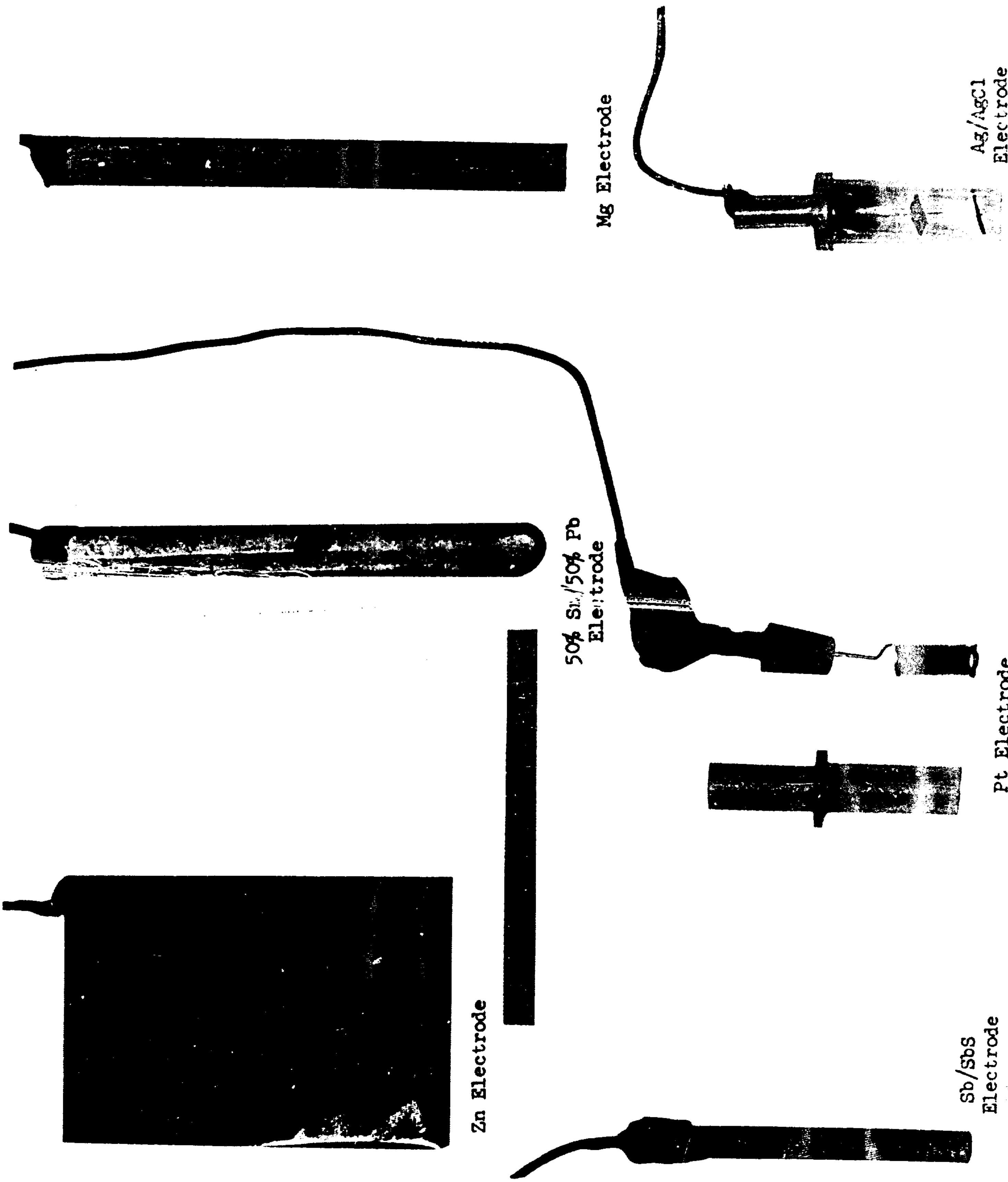


Figure 16. Various electrodes tested for use
with automatic control unit.

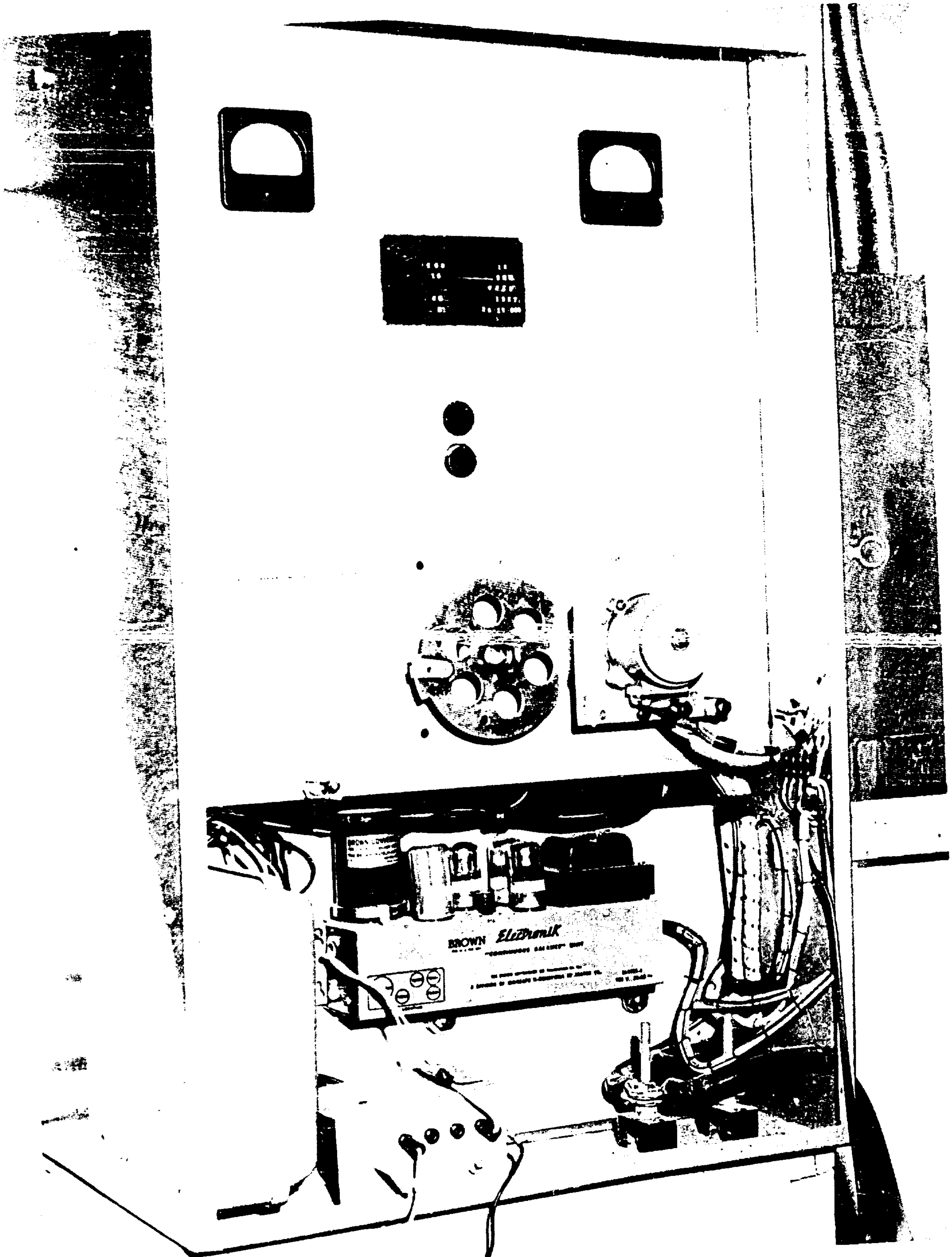
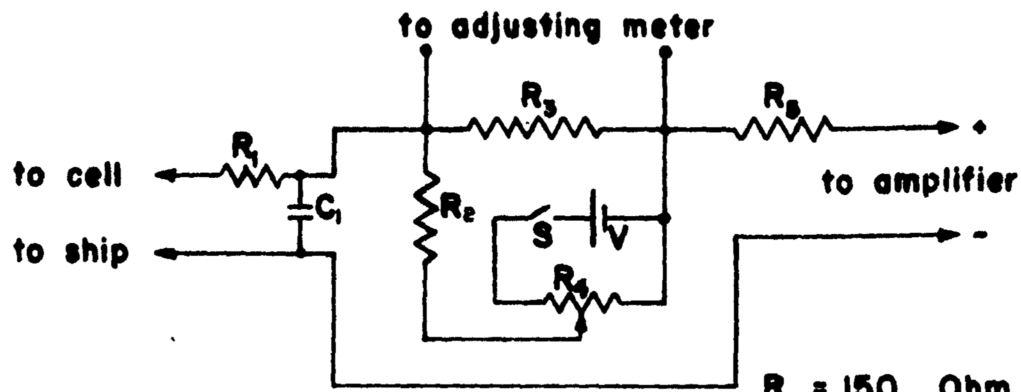


Figure 17. Automatic current control unit mounted on rectifier panel.



C_1 = 100 µfd.
S = Toggle switch
V = 1 ½ Volt battery

R_1 = 150 Ohm
R_2 = 560 Ohm
R_3 = 1 K Ohm
R_4 = 2.5K Ohm
R_5 = 220 Ohm

Fig. 18 REFERENCE VOLTAGE SCHEMATIC

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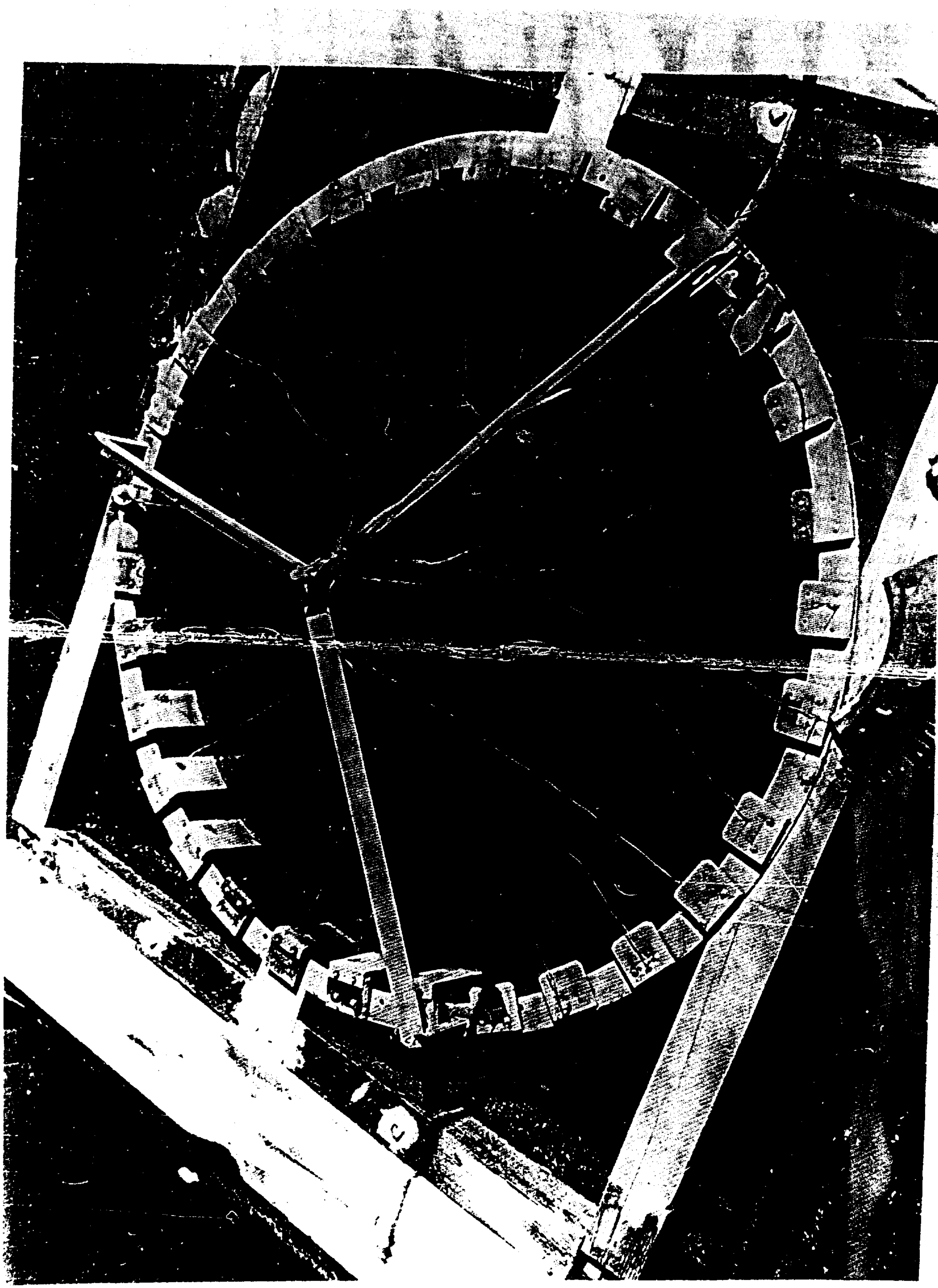


Figure 19. Float used to suspend panels and anode for evaluation of paints in conjunction with cathodic protection.

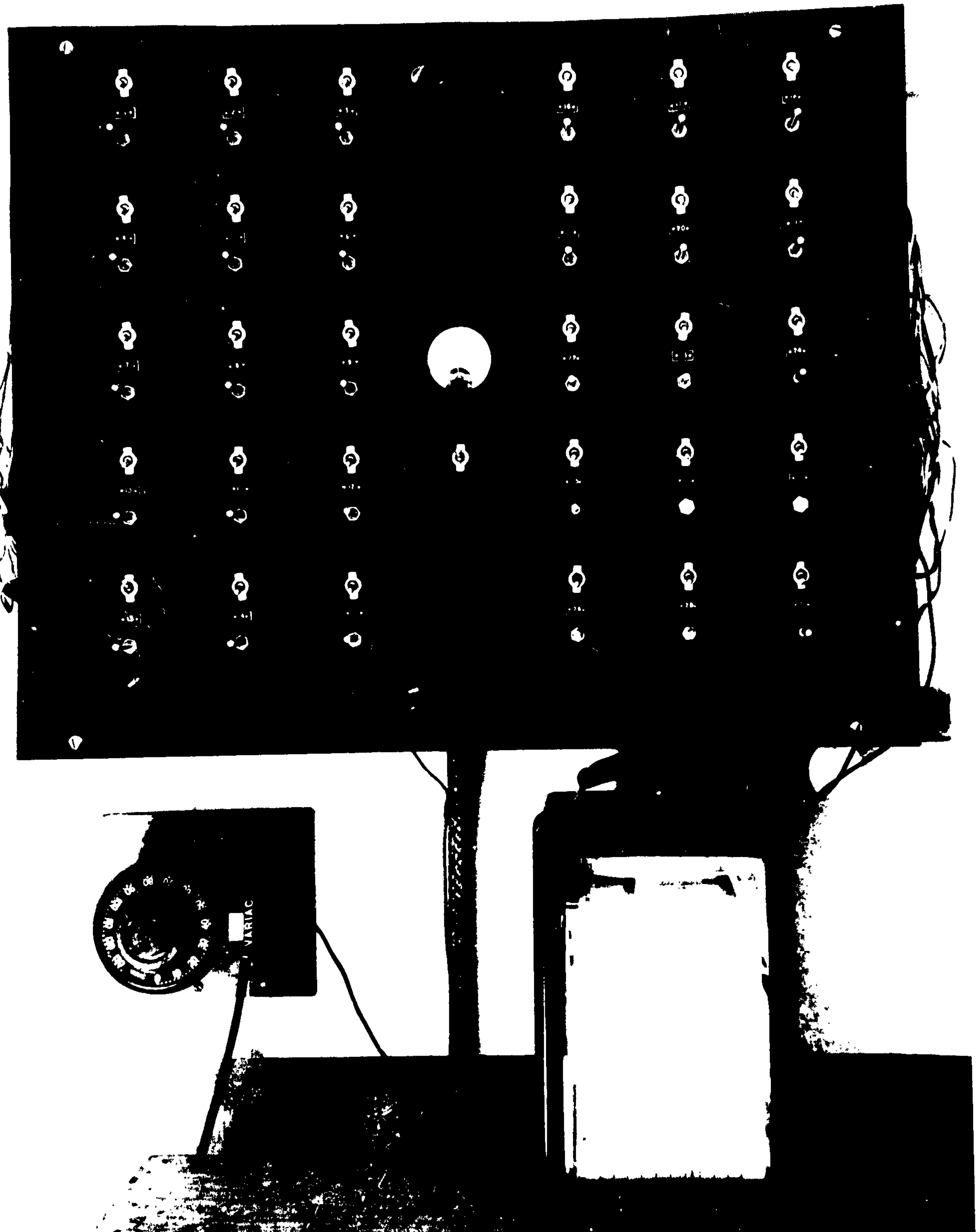
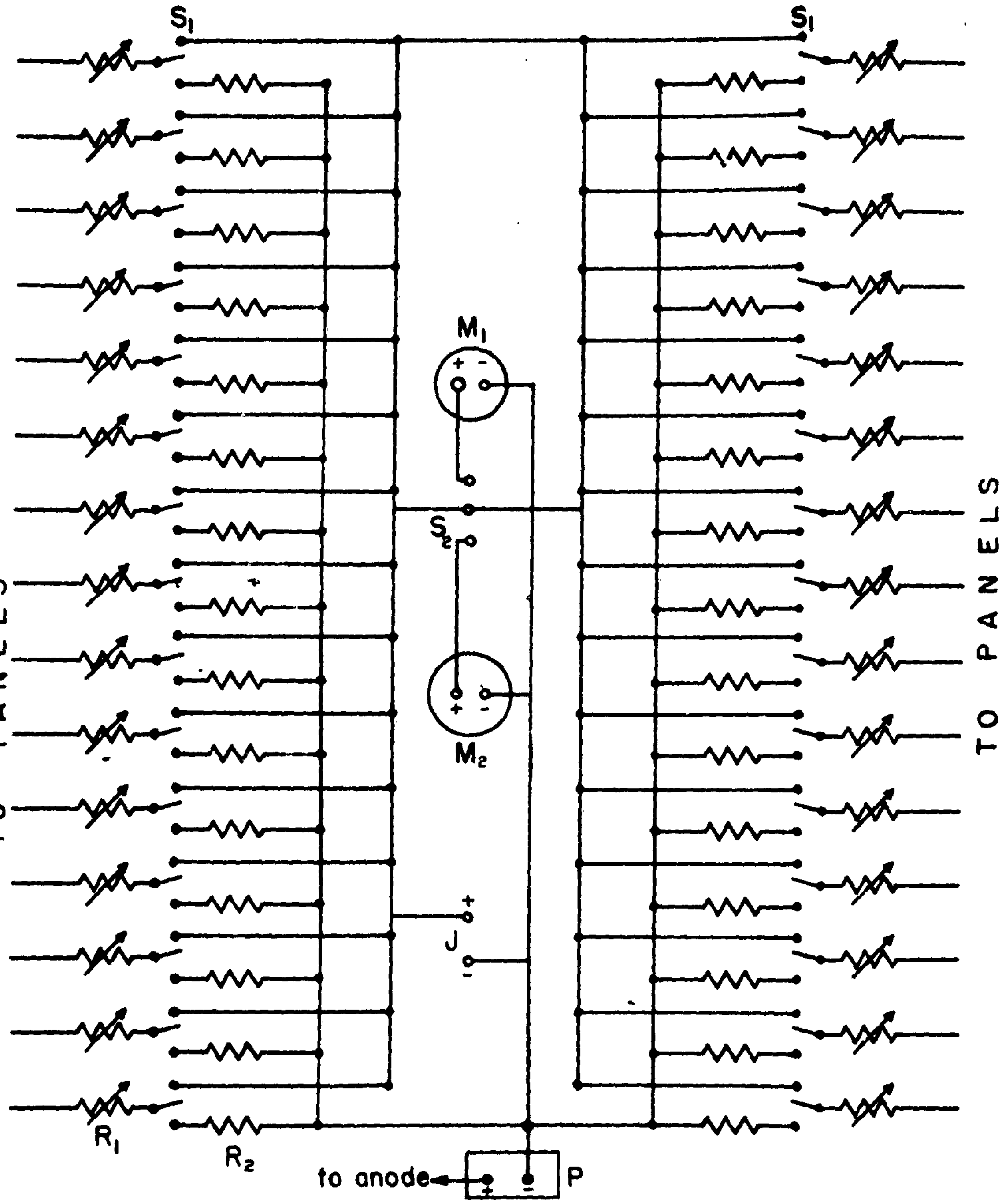


Figure [illegible]. Control panel for cathodic protection system used with [illegible]



S_1 = DPDT Toggle Switches
S_2 = 3 position DPDT Toggle Switch
J = Jacks for using external meter
P = Rectifier

R_1 = Control variable resistors
R_2 = Meter compensating resistors
M = 0-1 milliameter
M = 0-10 milliameter

Fig. 21 CONTROL SYSTEM FOR PAINT AND CATHODIC PROTECTION TEST

Figure 22. Laboratory set-up for preliminary tests of float coating and cathodic protection.